Embankment Dam and Spillway Relative Risk Procedures (for Asset Management/Maintenance)

Luc Chouinard – McGill University

Asset Management

Project Context

- Improve procedures for evaluating the current state of assets
  - Inspections performed on an annual basis and reports filed with government agencies
- Develop objective procedures for ranking maintenance priorities
  - Limited budgets
  - Ranking process must be uniform across all administrative units

Asset Management

Project Objectives

- Asset Management Strategy for:
  - Embankment dams
  - Spillways
  - *Concrete dams*

Asset Management

General principles

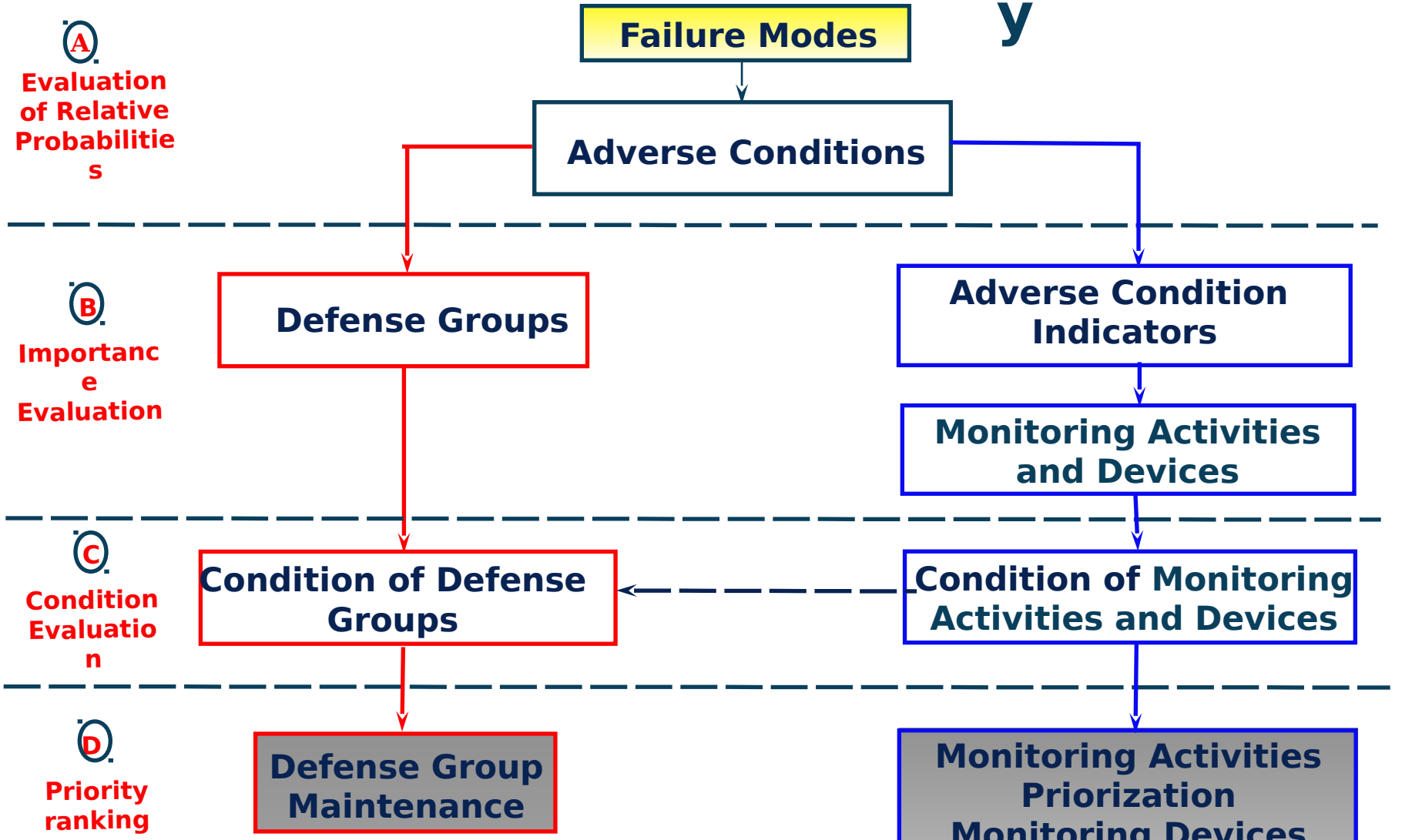
Identification and ranking of maintenance interventions.

- Current state is determined from site inspection and data from dam/spillway performance evaluation reports (~**component reliability** – REMR scale)
- Importance is based on the contribution of various components to dam/spillway performance (~**for system reliability**), specific for each facility.
- Ranking is established as a function of relative importance and current state of dam components

Asset Management for Embankment Dams

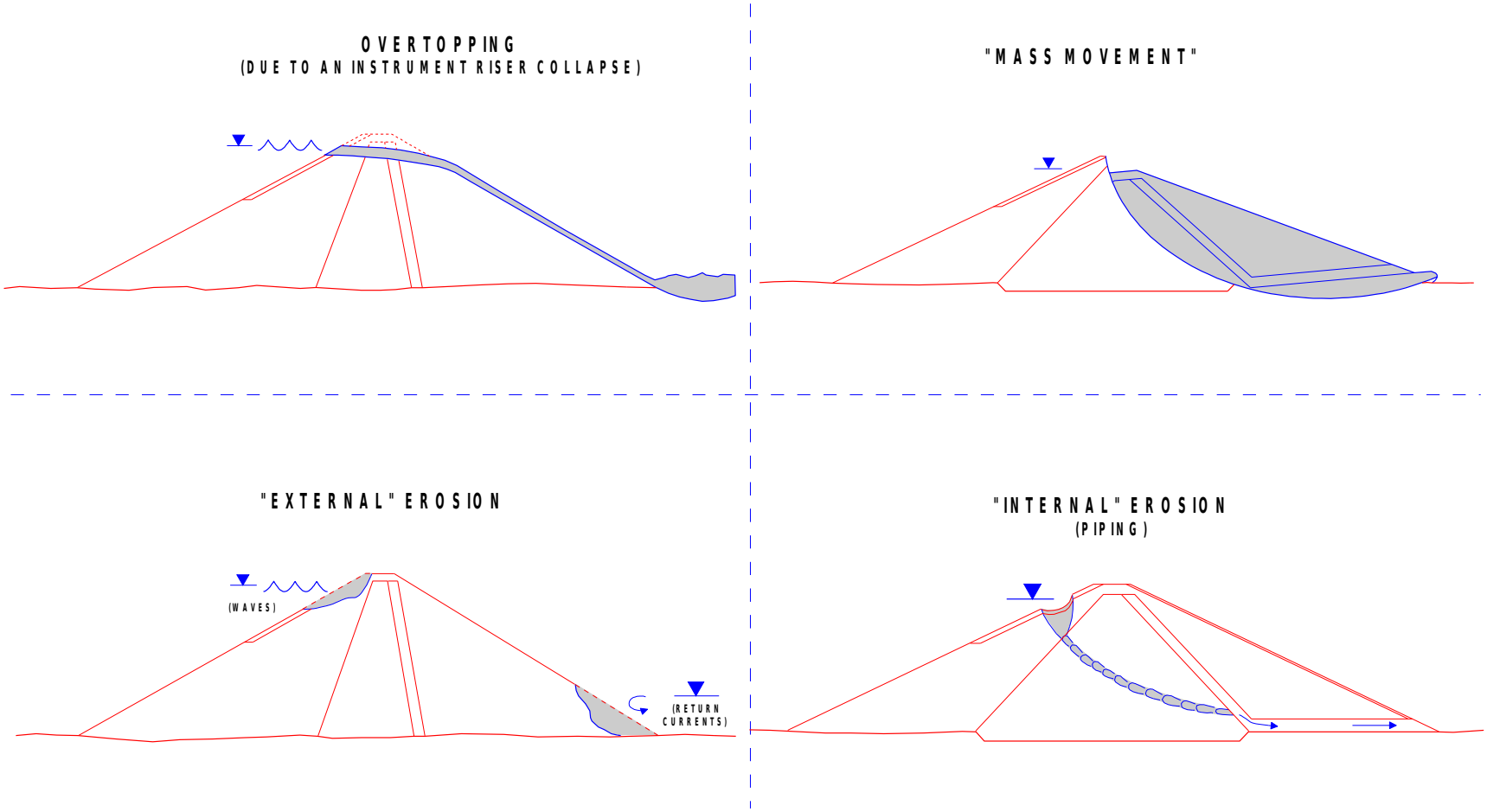
- Initiated in 1995 (Hydro-Quebec with USACE)
- Tested by Hydro-Quebec in 1999 on 25 dams
- Application Guide developed in 2000 by Hydro-Quebec (reduce uncertainty)
- Gradually introduced in all districts
- Adopted by Manitoba-Hydro and Cemagref (France)

Asset Management Methodology



Asset Management

THE FOUR MAJOR FAILURE MODES FOR EMBANKMENT DAMS



DAM FAILURE DEFINITION: UNCONTROLLED RELEASE OF RESERVOIR

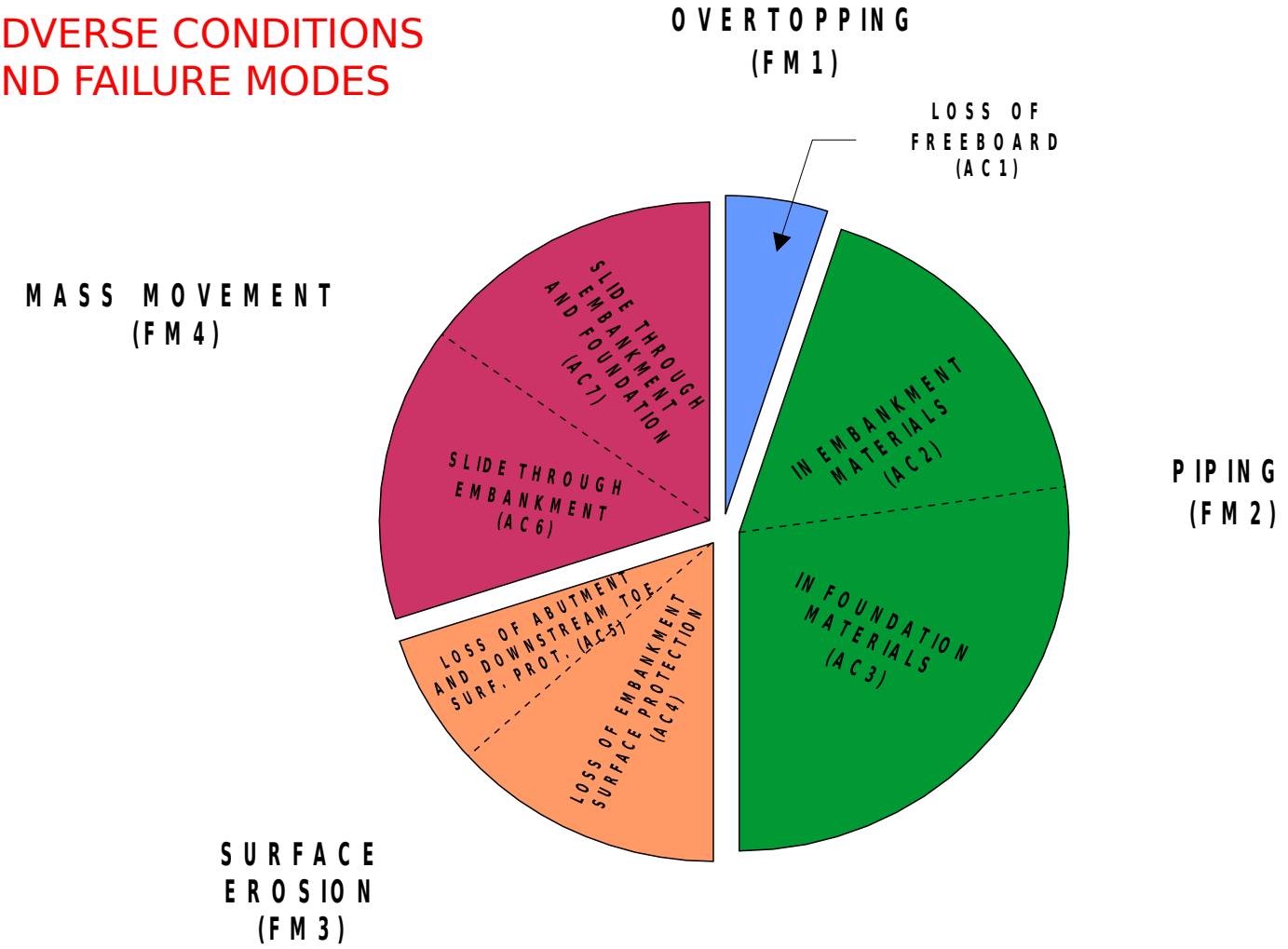
S_4RUPT.GRF

Asset Management

Positive attributes	• Rock abutment surfaces • Low seismicity location • Low exposition to wave attack • Non erodible core • Embankment made up of filtering material • Non erodible rock foundation • Filters designed according to modern practice • Reservoir touches dyke only near maximum water level • Freeboard dyke on rock foundation
Negative attributes	• Spillway operated by other owner • Totally submerged downstream toe • Locally submerged downstream toe • Large water seepage at downstream toe • No chimney drain in homogeneous dyke • Heterogeneous and permeable foundation materials • No positive cutoff in permeable soil foundation • Vertical or sub-vertical abutment • Low freeboard • Potential sinkhole formation near instrumentation risers • High seismicity location

Asset Management

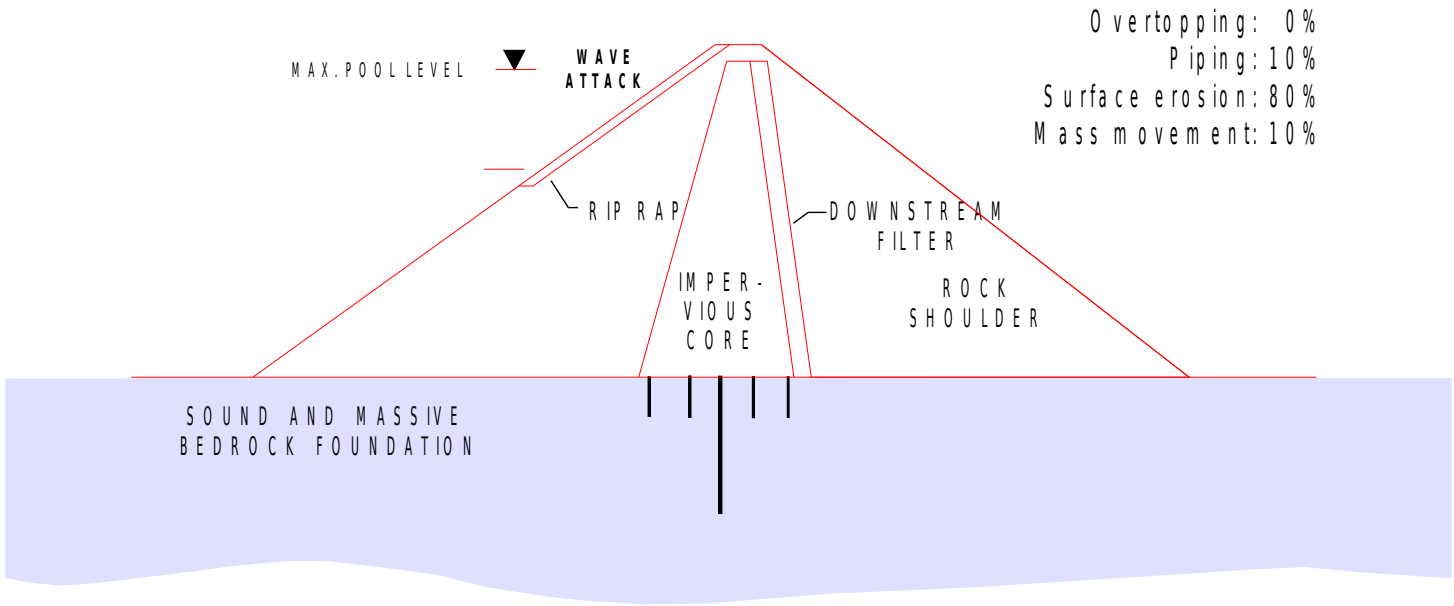
ADVERSE CONDITIONS
AND FAILURE MODES



Asset Management

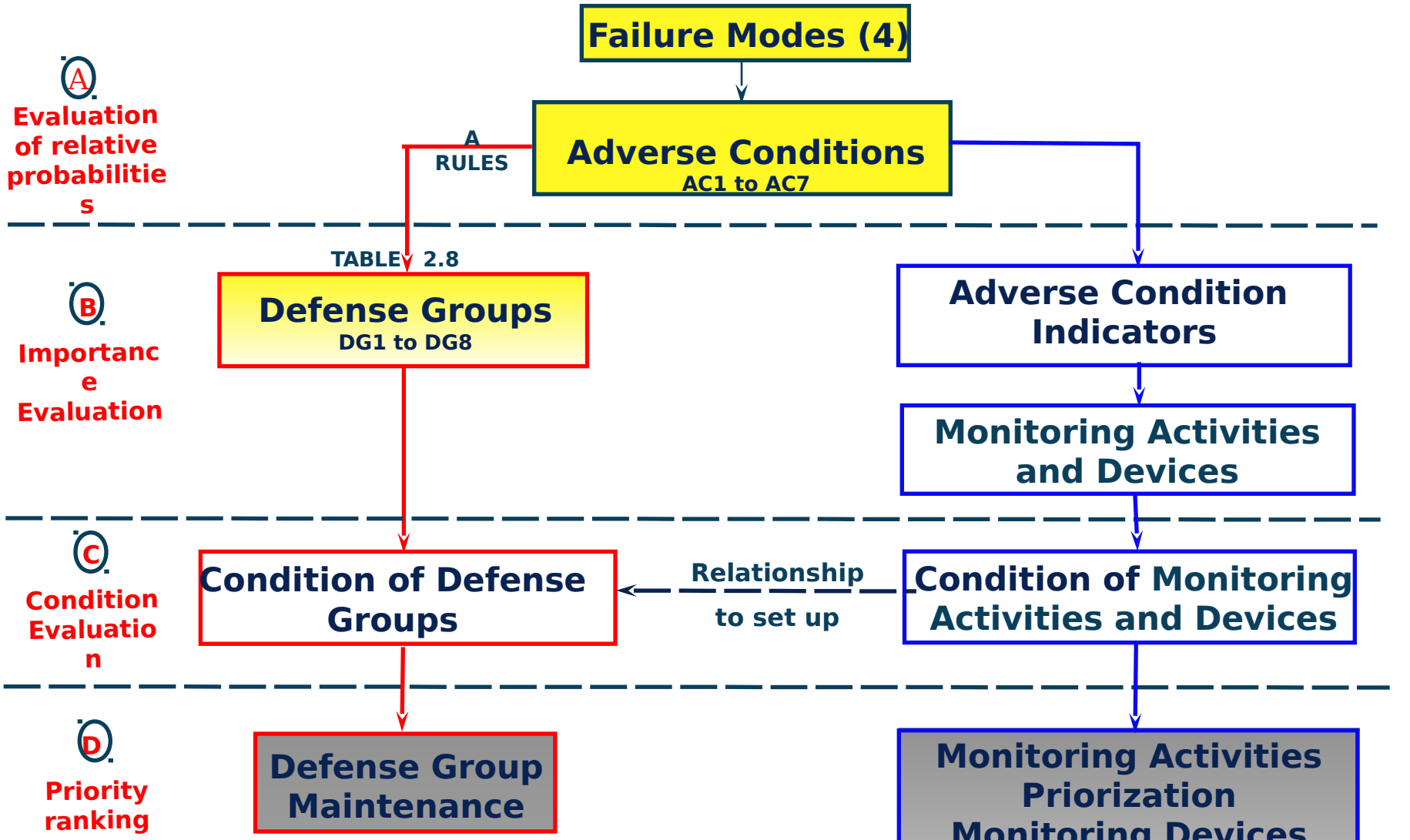
FAMILY I

ROCK (OR GRANULAR) EMBANKMENT
ON SOUND AND MASSIVE BEDROCK FOUNDATION



MAIN CONCERN:
RIPRAP EROSION BY WAVE ATTACK
IN DIFFICULT CLIMATE

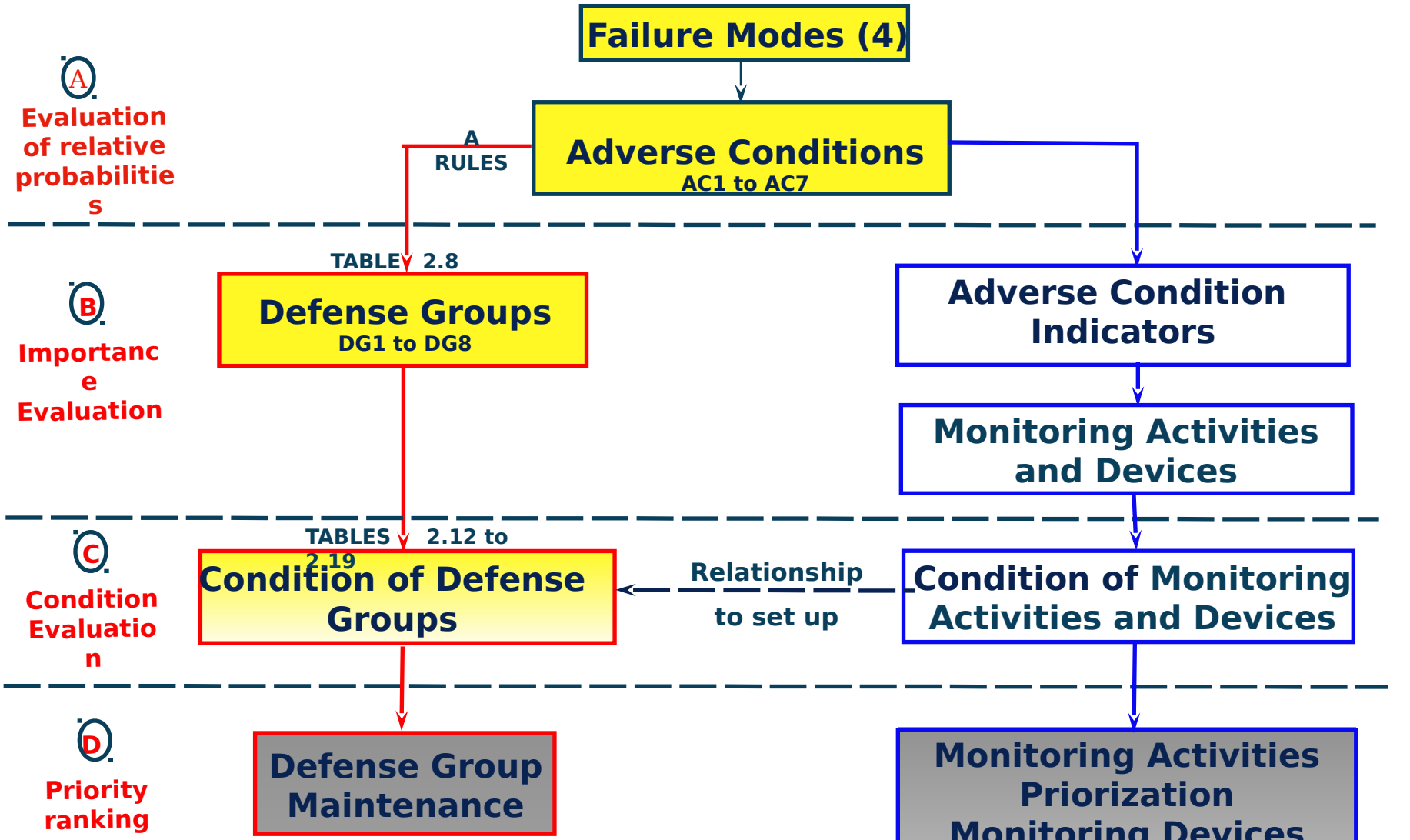
Asset Management



Asset Management

Defense Groups (DG)	Components
DG1. Maintaining nominal crest elevation	Top of dam
DG2. Filtration control in embankment	Engineered filter materials placed within embankment to prevent the migration of fines
DG3. Pressure control in embankment	Chimney drains, blanket drains, finger drains, im-pervious core, etc.
DG4. Filtration control in foundation	Engineered filter materials placed over foundation outside embankment to prevent the migration of fines
DG5. Pressure control in foundation	Relief wells, toe drain, positive cutoff, upstream impervious blanket, etc.
DG6. Upstream slope protection	Rip-rap, upstream concrete blanket, etc.
DG7. Crest and downstream slope protection	Stone, vegetation cover, etc.
DG8. Abutment and downstream toe protection	Stone, vegetation cover, etc.

Asset Management



Asset Management

REMR Scale

Zone	Condition index	Condition description	Recommended action
1	85 to 100	**Excellent:** No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	**Good:** Only minor deterioration or defects are evident.	
2	55 to 69	**Fair:** Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	**Marginal:** Moderate deterioration. Function is still adequate.	
3	25 to 39	**Poor:** Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	**Very Poor:** Extensive deterioration. Barely functional.	
	0 to 9	**Failed:** No longer functions. General failure or complete failure of a major structural component.	

Asset Management

- Condition Table for a Defense Group
  - Define its function (performance based)
  - Define what is an excellent condition (100)
  - Define what is a failed condition (0)
  - Identify indicators of condition
    - Physical measurement
    - Performance level
    - Qualitative observation

Asset Management

Defense Group DG2. Filtering control in embankment									
Ideal condition	No migration of fines with a designed filtering system.								
Failed condition	Persistent migration of fines.								
	0-9	**10-24**	**25-39**	**40-54**	**55-69**	**70-84**	**85-100**		
Condition description	**Failed**	**Very poor**	**Poor**	**Marginal**	**Fair**	**Good**	**Excellent**	**Given index**	**Remarks and justifications**
Indicators DG IND									
IND2.1. Existence of turbid flows or sand deposition at uncontrolled seepage location in embankment									
• no evidence							**100**	**100**	**Clear seepage**
• evidence of prior occurrence			**X**	**X**	**X**				
• actively occurring	**X**	**X**							
IND2.2. Sinkholes or depressions in embankment									
• no evidence							**100**	**100**	**No noticeable deformations**
• evidence of prior occurrence			**X**	**X**	**X**				
• actively occurring	**X**	**X**							
IND2.3. Known defect, but with no indicator of distress			**X**	**X**	**X**	**X**			

Examples of known defects: poor design of internal filter or drainage zone within embankment.

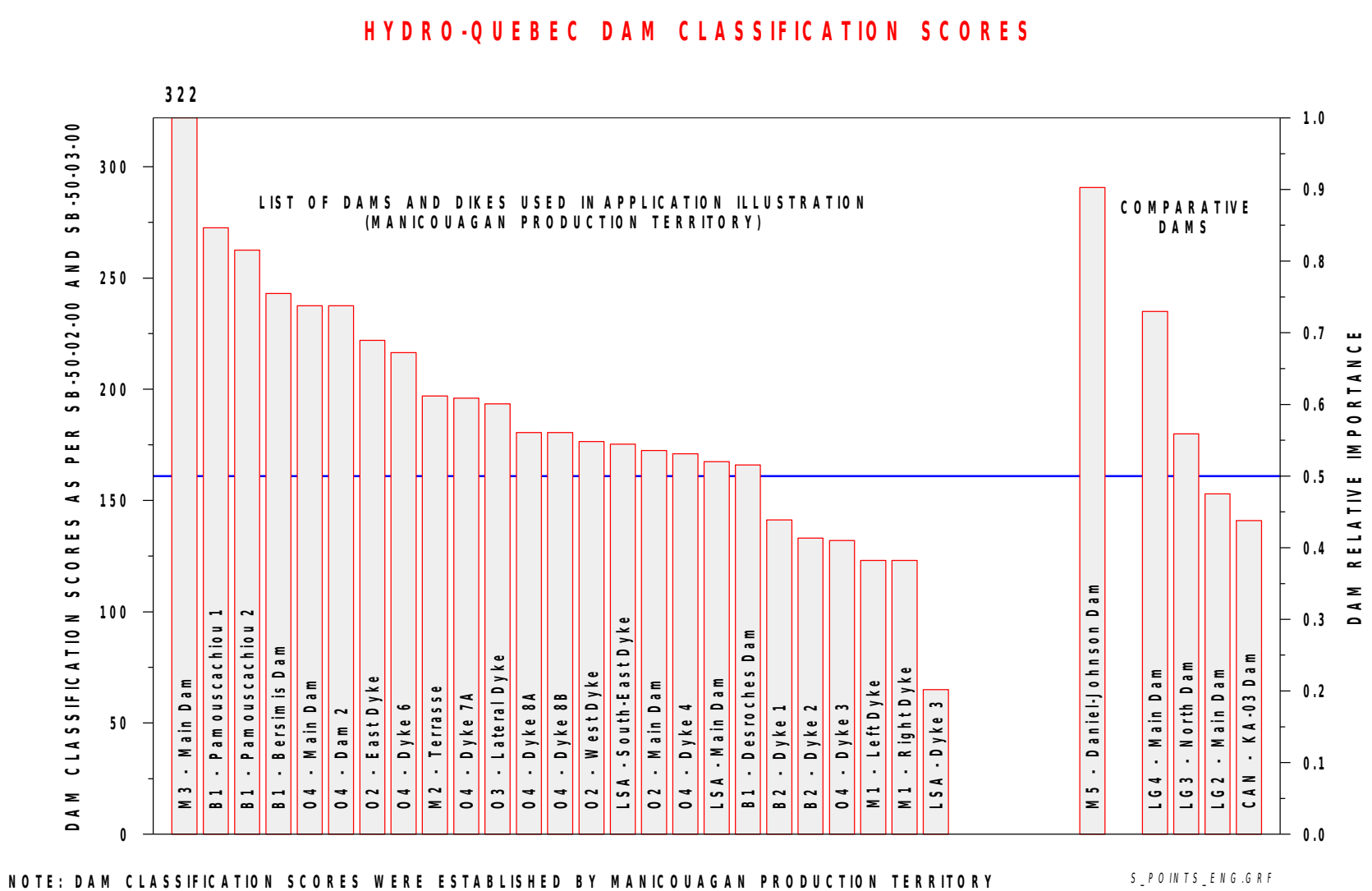
Asset Management

$$PR_{DG_{i,j}} = I_{Dam_j} \cdot I_{DG_{i,j}} \cdot \frac{(100 - CI_{DG_{i,j}})}{100}$$

where

$CI_{DG_{i,j}}$	condition index of Defense Group DG_i of Dam_j
$I_{DG_{i,j}}$	relative importance of Defense Group DG_i of Dam_j
I_{Dam_j}	relative importance of Dam_j
$PR_{DG_{i,j}}$	priority ranking of Defense Group DG_i of Dam_j

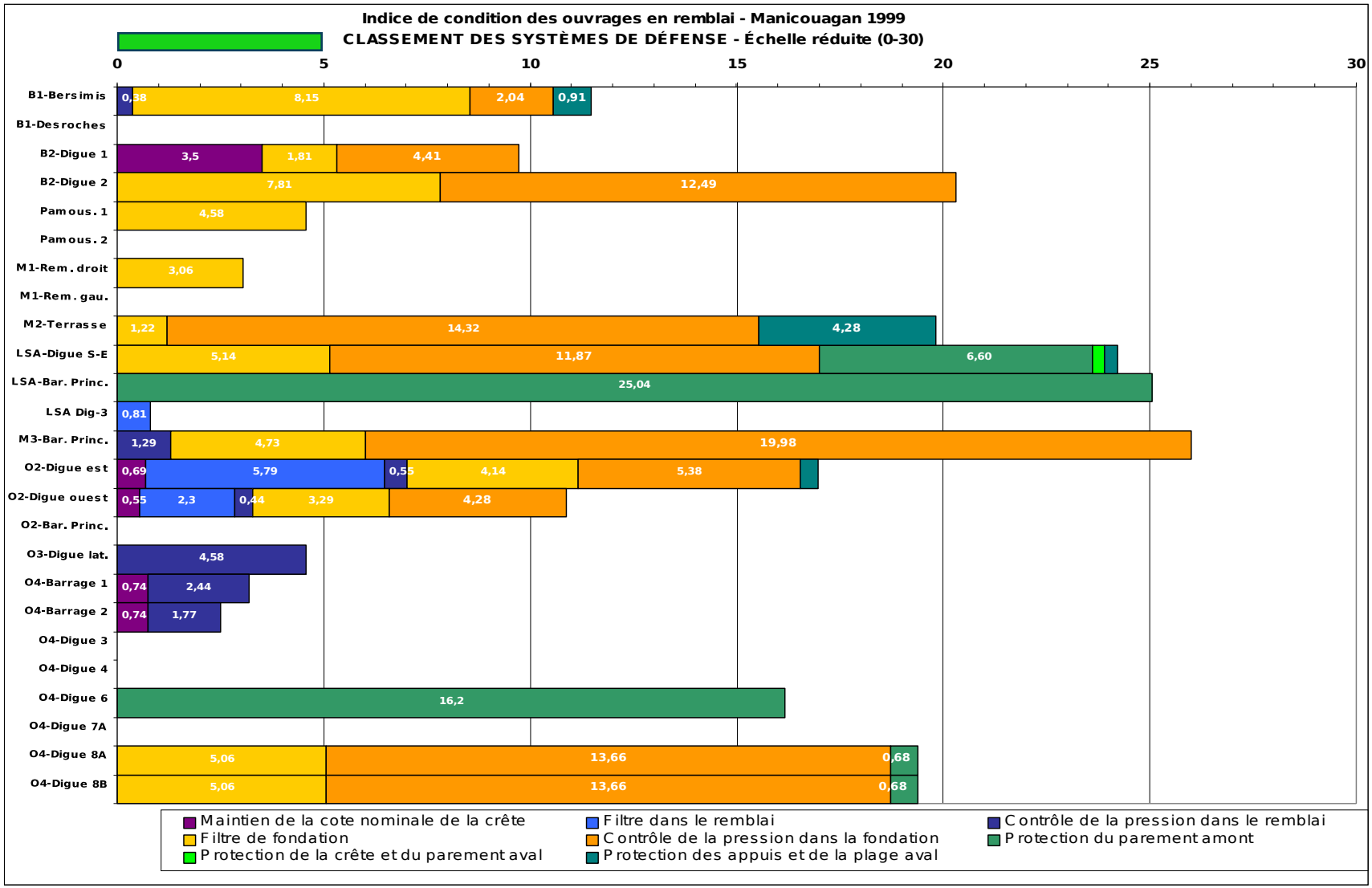
Asset Management



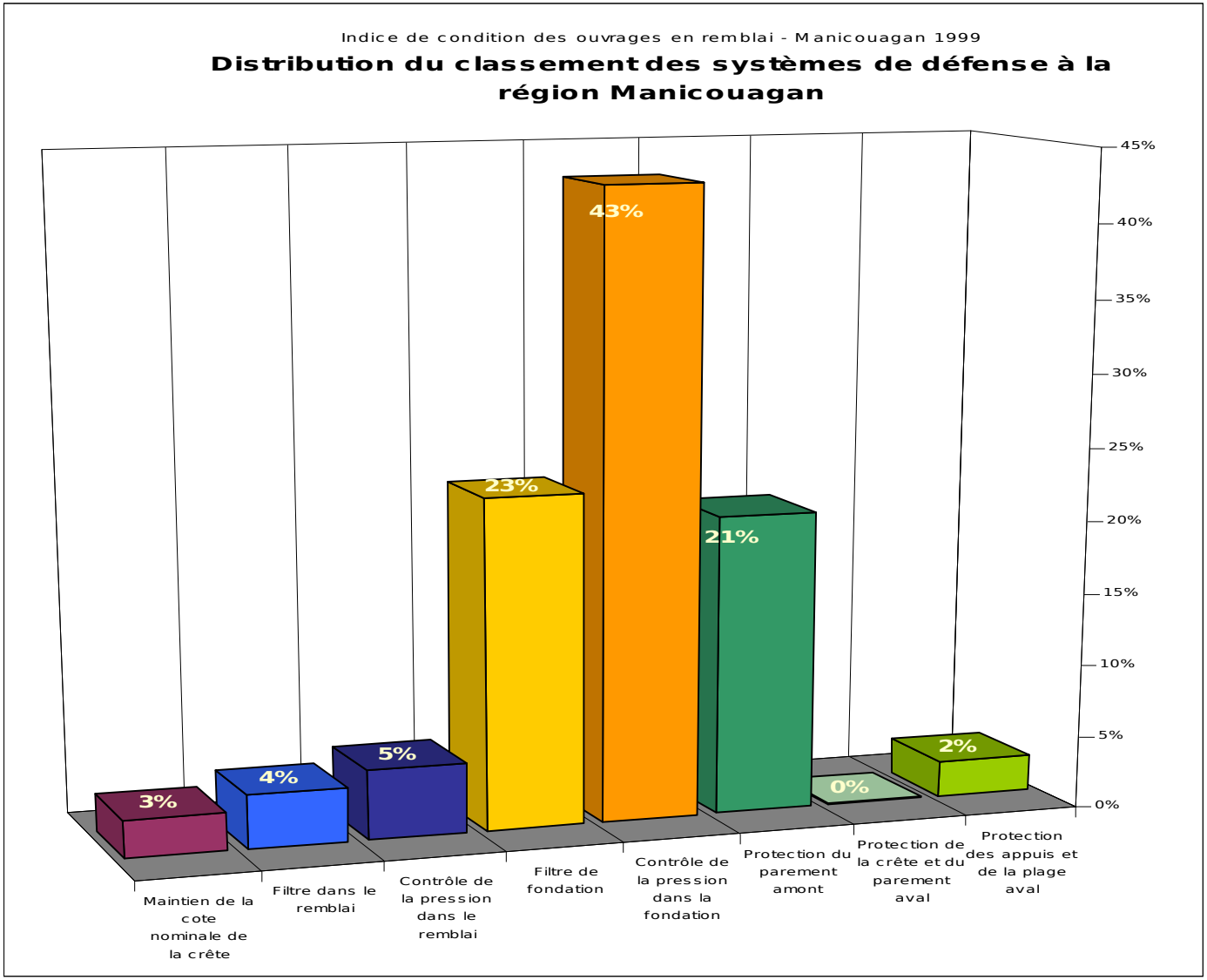
Asset Management

Pressure control in foundation

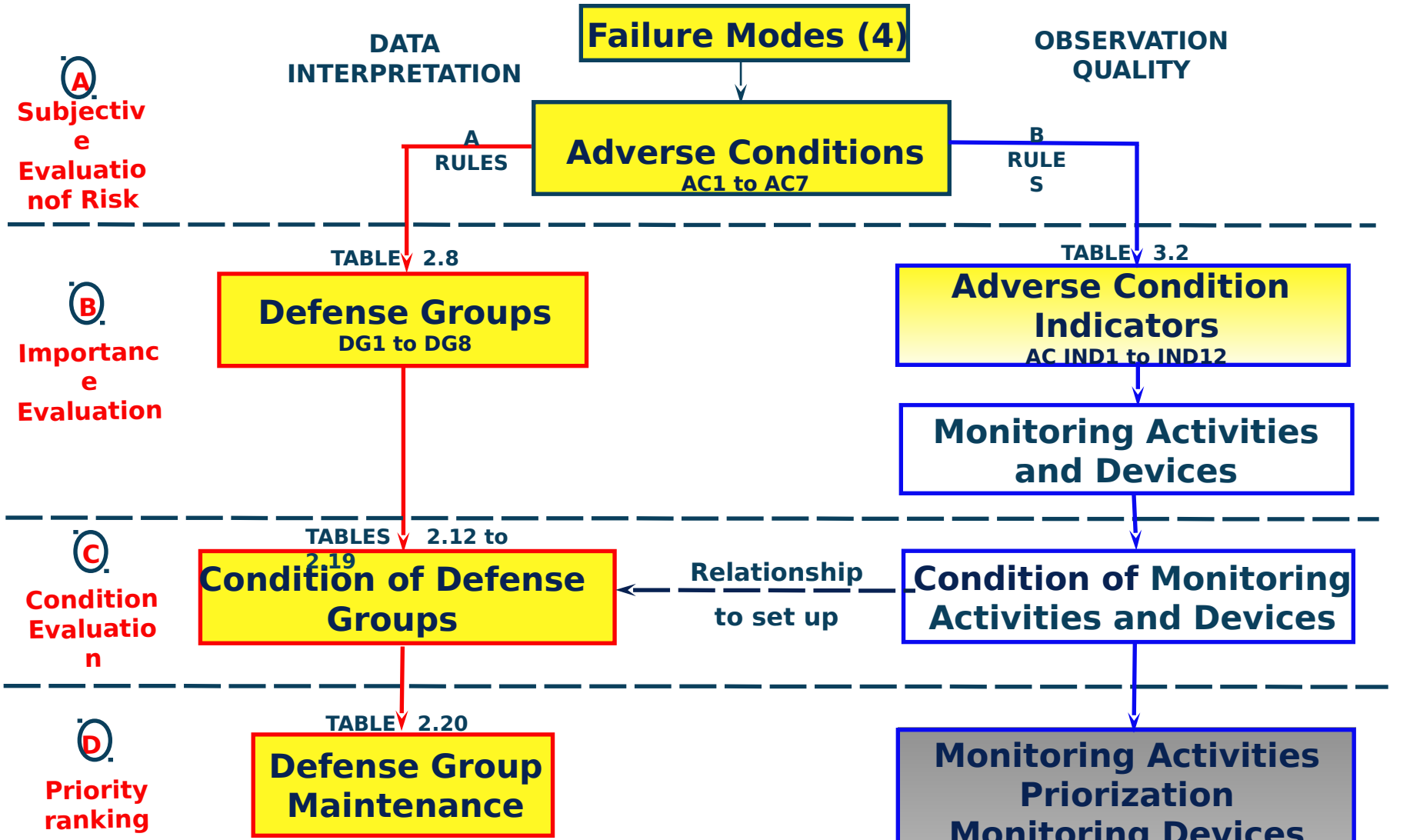
Upstream slope protection



Asset Management



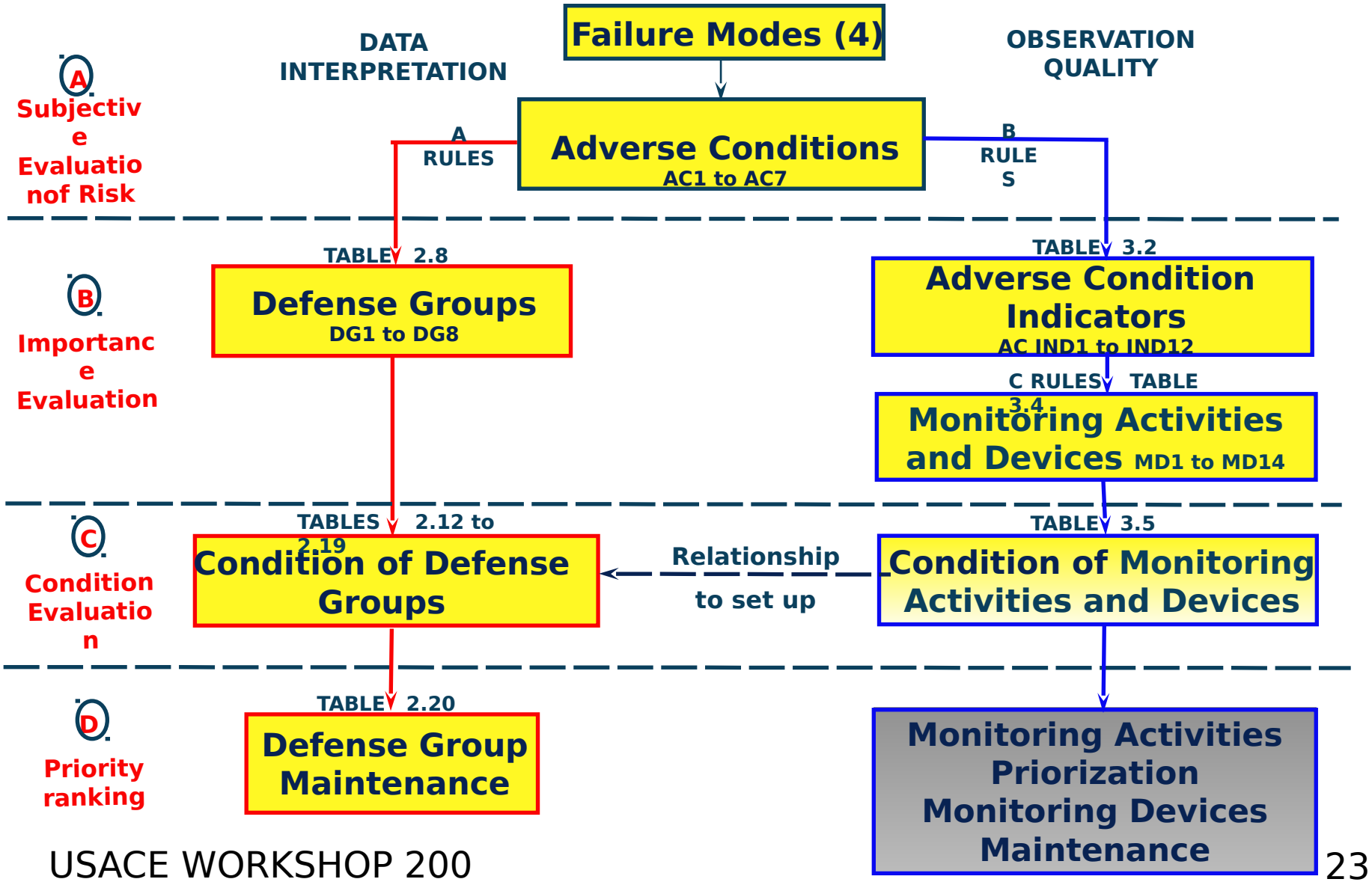
Asset Management



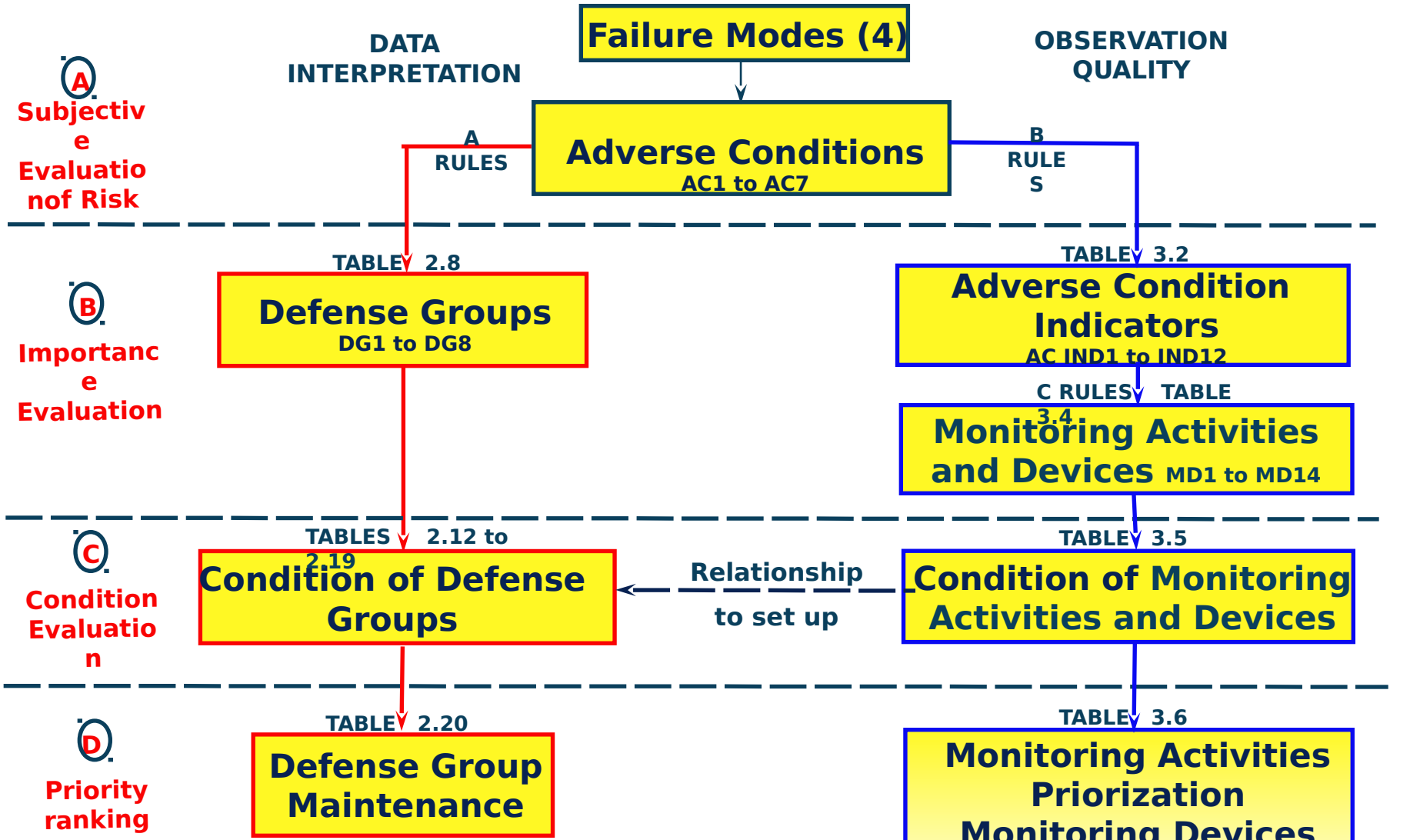
Asset Management

	Adverse Condition Indicators (AC IND)	Definitions
Deformation	AC IND1. Change in geometry on upstream slope	Visible or measurable differences between design geometry and current conditions for the upstream slope.
	AC IND2. Change in geometry on crest	Visible or measurable differences between design geometry and current conditions for the crest.
	AC IND3. Change in geometry on downstream slope	Visible or measurable differences between design geometry and current conditions for the downstream slope.
	AC IND4. Change in geometry on downstream toe area	Visible or measurable differences between design geometry and current conditions for the downstream toe area.
	AC IND5. Relative movement between components	Visible or measured evidence of relative displacements between objects resting on the embankment dam and those resting on the foundation.
Seepage	AC IND6. Change in controlled seepage	Seepage quantities measured at control locations (e.g. toe drains, pressure relief wells)
	AC IND7. Uncontrolled seepage on downstream slope	Unplanned and unfiltered surface seepage on the downstream slope (turbid refers to removal of soils).
	AC IND8. Uncontrolled seepage on downstream toe area	Unplanned and unfiltered surface seepage on the downstream toe area (turbid refers to removal of soils).
Pressure	AC IND9. Piezometric levels in embankment	Referring either to the magnitude or as inferred from flow net to calculate gradients.
	AC IND10. Piezometric levels in foundation	Referring either to the magnitude or as inferred from flow net to calculate gradients.
Vegetation	AC IND11. Change in vegetation on downstream slope	Visible changes in the amount or coloration of vegetation on the embankment dam or adjacent regions in the general vicinity of the downstream slope.
	AC IND12. Change in vegetation on downstream toe area	Visible changes in the amount or coloration of vegetation on the embankment dam or adjacent regions in the general vicinity of the downstream toe area.

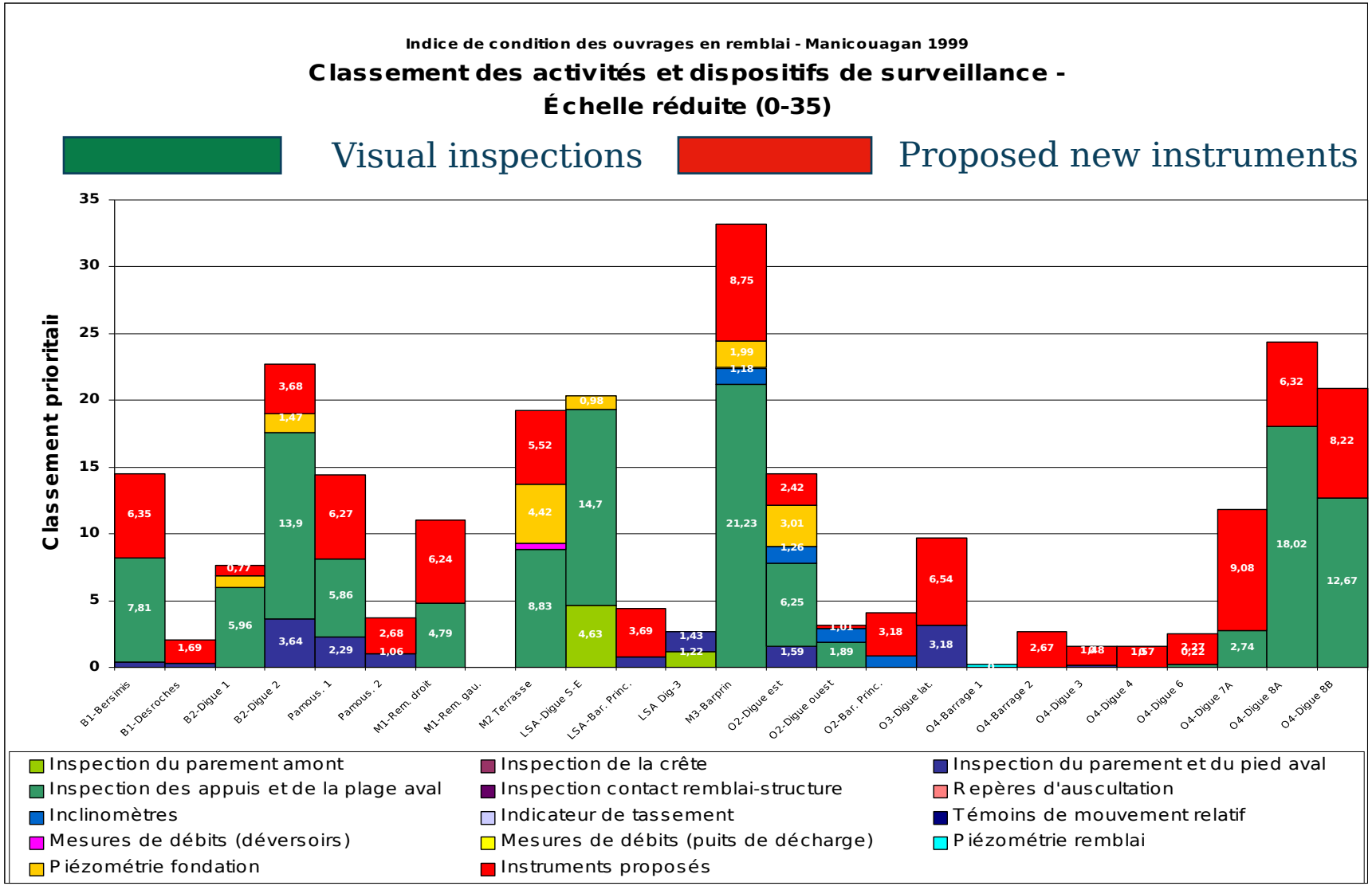
Asset Management



Asset Management



Asset Management



Asset Management

Spillways

Asset Management

Partners

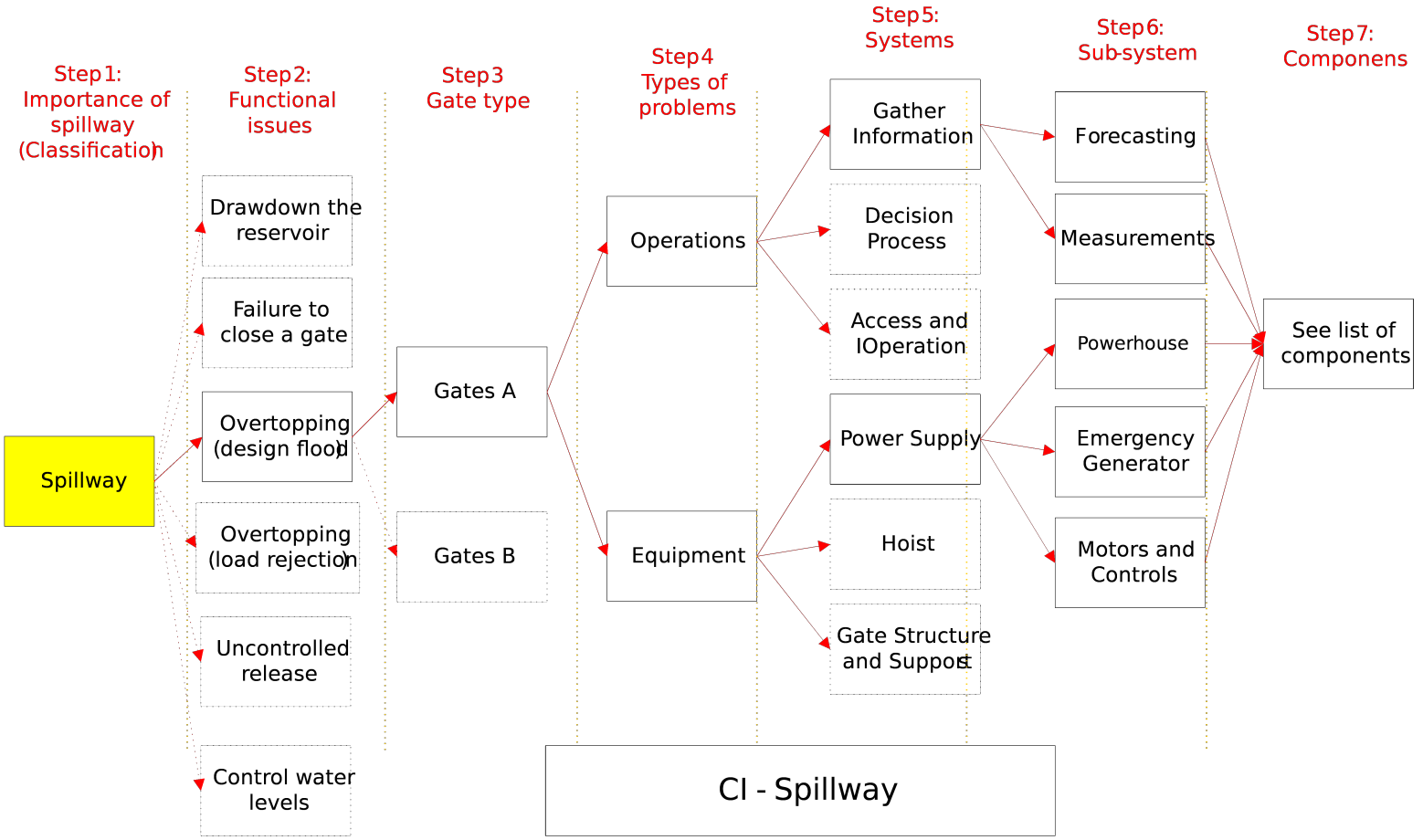
- U.S. Army Corps of Engineers
- Manitoba Hydro
- Ontario Power Generation
- U.S. Bureau of Reclamation
- Hydro-Québec
- McGill University

Asset Management

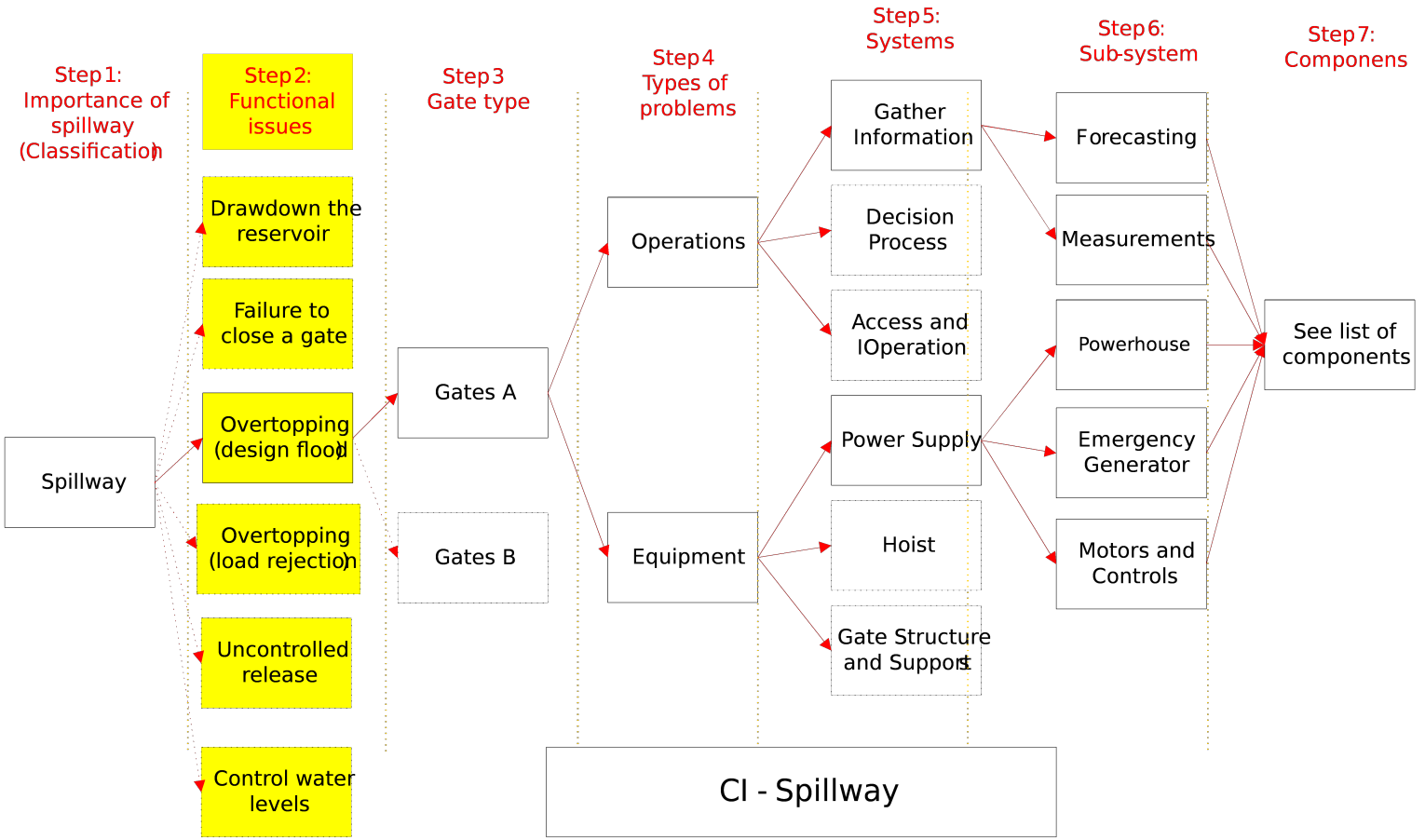
Importance Factors

- Conceptual model of the spillway (number of gates, lifting devices, etc.)
- Identify major functional issues associated with the spillway
- Relative importance of components for each function (factors considered: role of the component,response time, reaction,…)

Asset Management



Asset Management



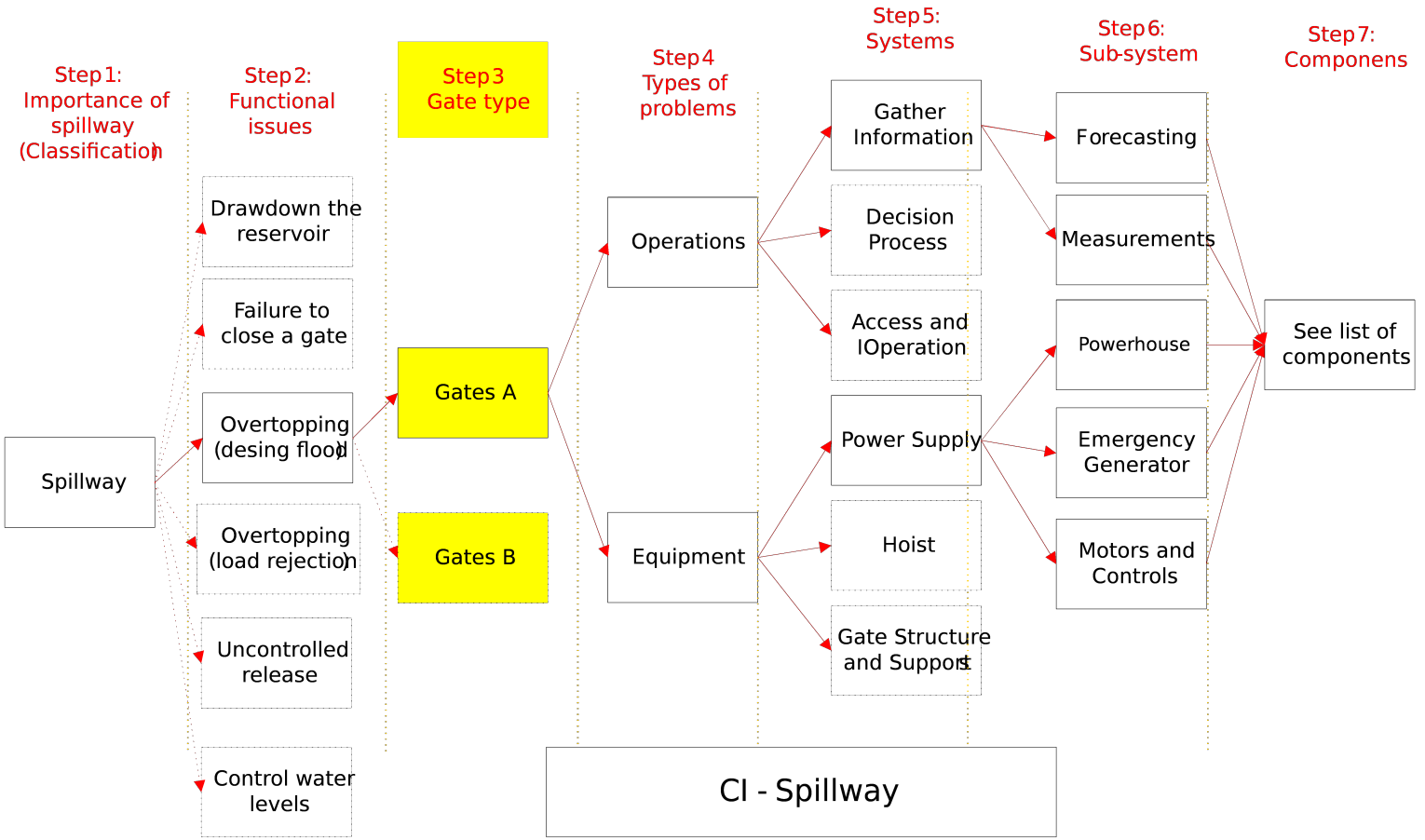
Asset Management

Step 2

Functional issues	Definition
Prevent overtopping during a design flood	Ability to operate all gates to achieve full spilling capacity.
Prevent overtopping during load rejection	Ability to spill the powerhouse flow during loa rejection
Prevent an unintentional opening of the gates	Structural failure of a gate (blowout) or unintended opening of gate due to inaccurat information or a failure of automatic controls
Prevent failure to close a gate	Failure to close a gate due to equipment failu or failure to recognize the need to close a ga due to inaccurate information
Drawdown the reservoir	Ability to drawdown the reservoir to prevent structural failure of the dam or foundation.
Control water levels	For navigation, recreation, water supply,etc.

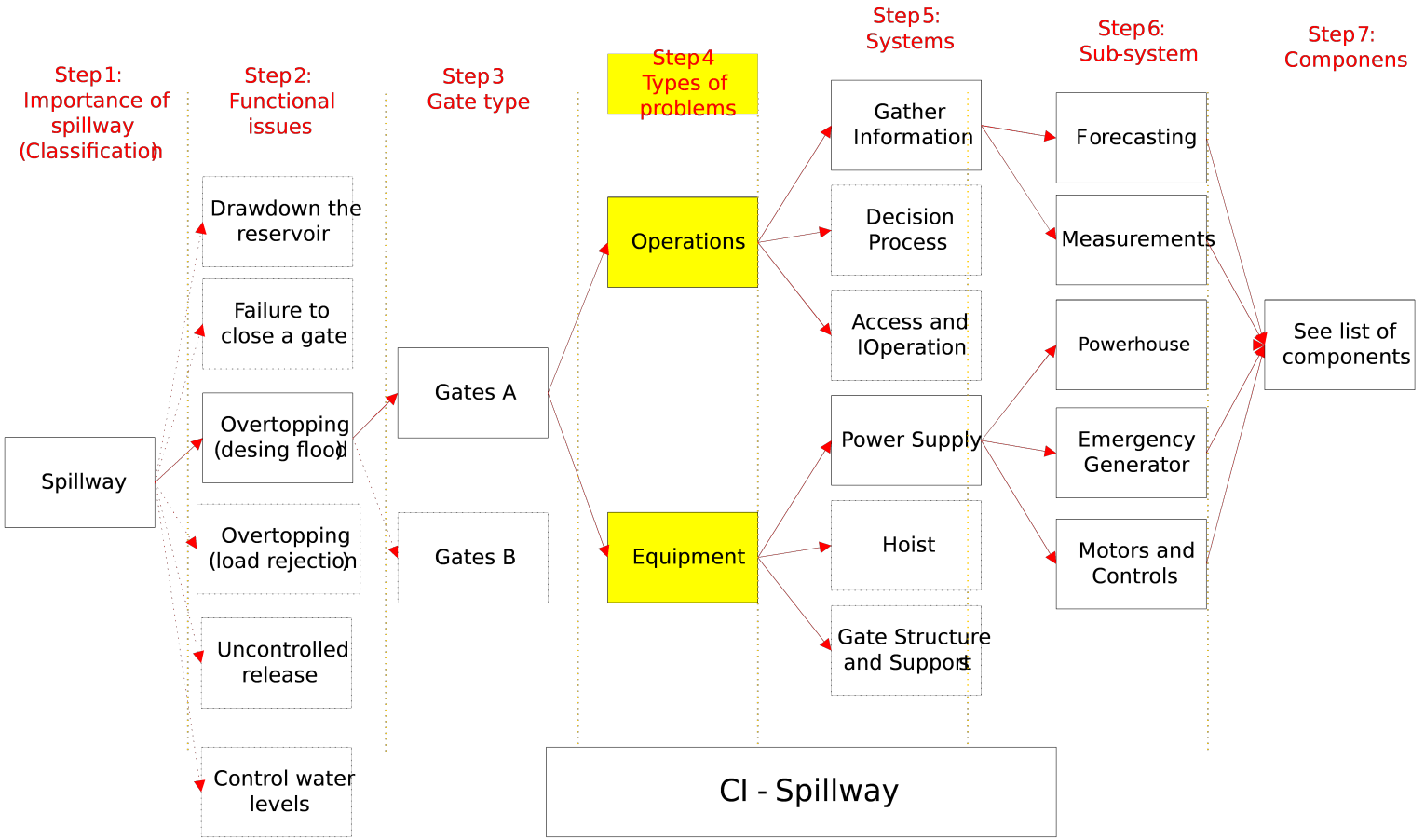
Asset Management

Spillway



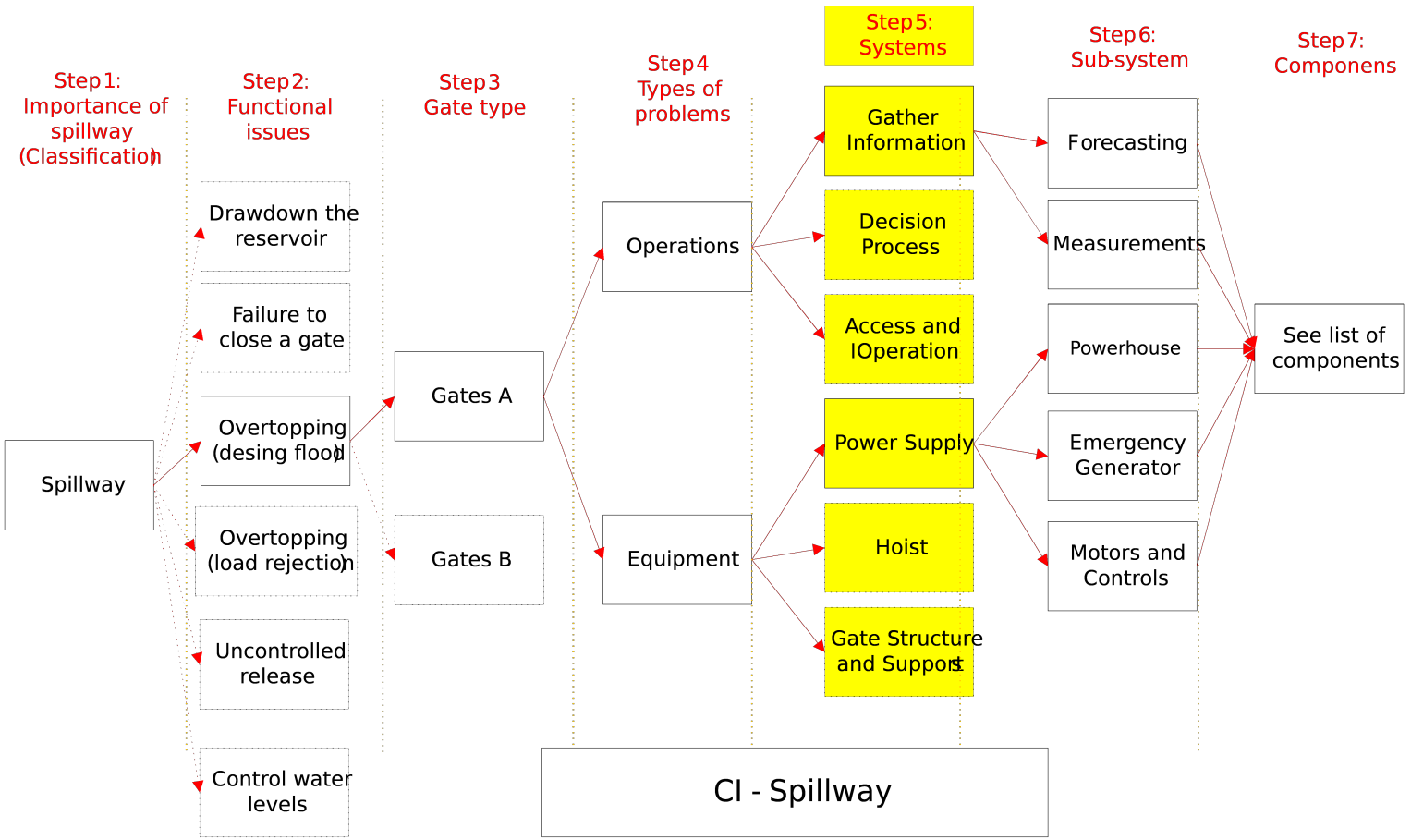
Asset Management

Spillway

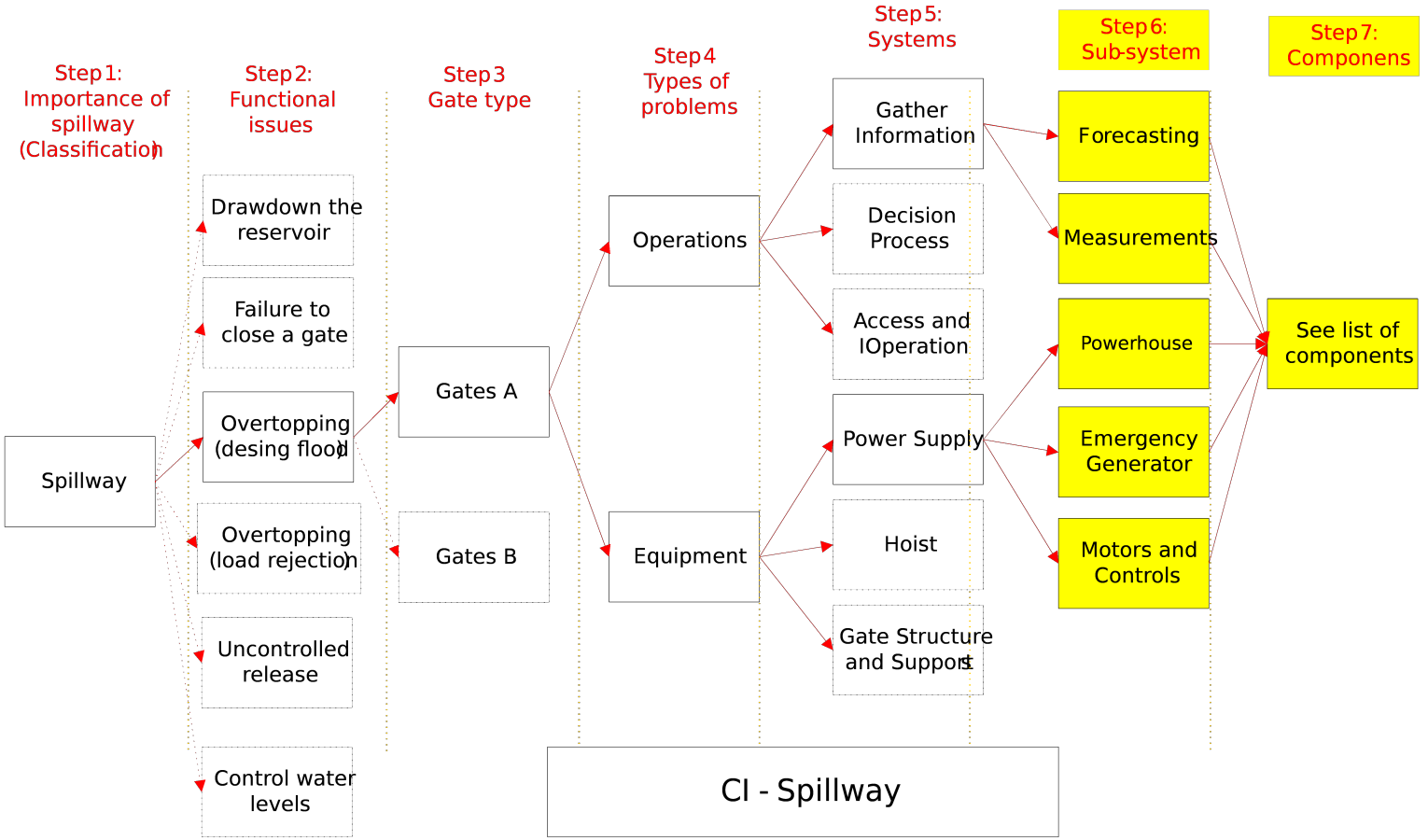


Asset Management

Évacuateur



Asset Management



Asset Management

Screw and Nut (Screw-type hoist)									
Function	Transfer shaft rotation into gate movement								
Excellent	No warping, no wear, geometry according to specs, uncontaminated grease .								
Failed	Warped enough to jam the mechanism, broken, split, missing threads, enough surface damage/corrosion to cause excessive friction								
	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
No warping, or damage, or wear with adequate lubrication and geometry and works as designed							X		
Surface Contaminants on grease or slight warping on screw with some damage or wear to threads of nut					X	X		60	Slight warping of a screw
Inappropriate lubrication			X	X	X				
Excessive friction/noise, vibration and jumping, presence of metal shavings		X	X						
Warped enough to jam the mechanism; broken, split, missing threads; enough surface damage/corrosion to cause excessive friction	X								

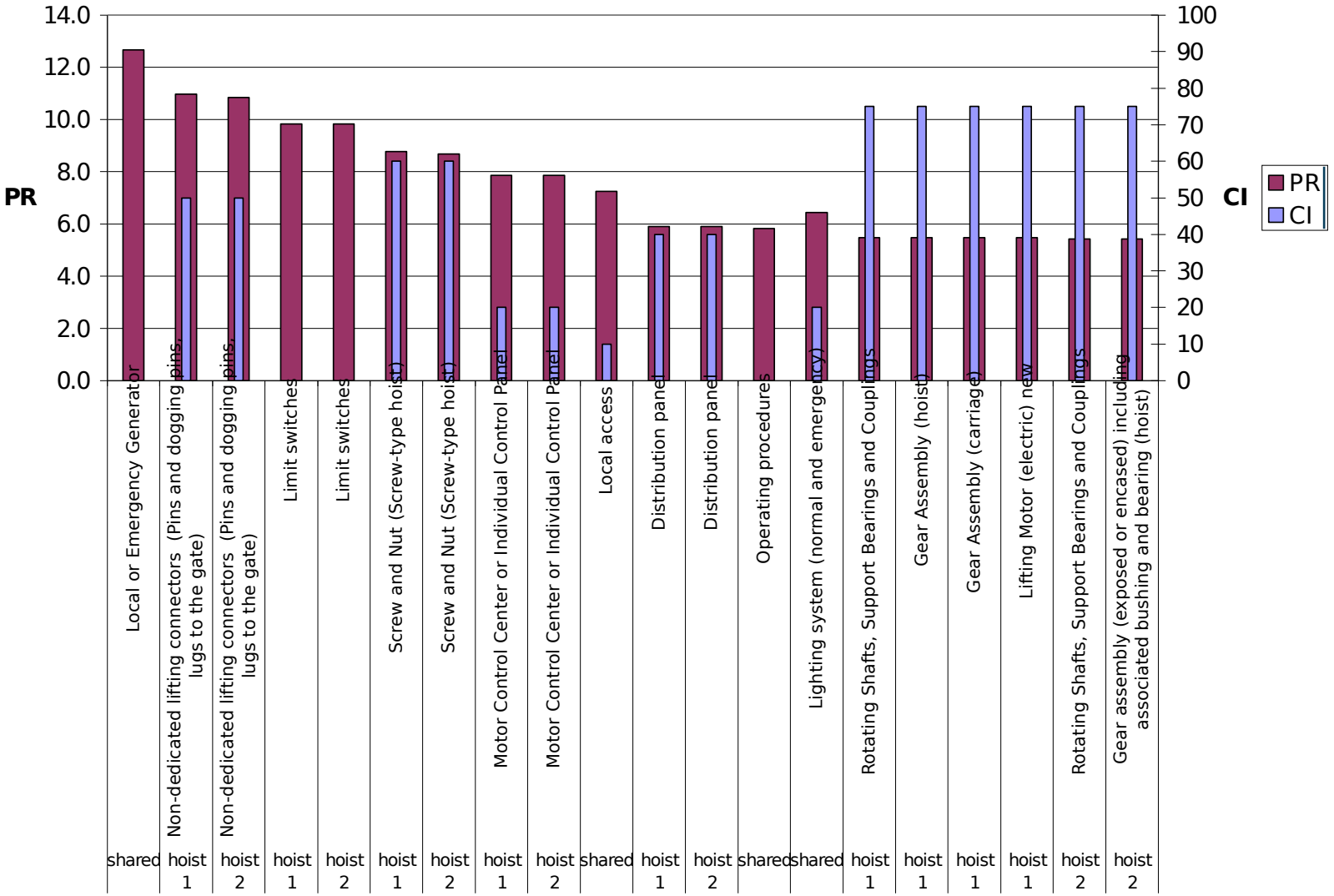
Claude Lemire

Raymond St-Jacques

Écrous ont été changé sur le chariot 2.

Does this category apply to the dam being evaluated ?	**y**	(y/n)
CI representing this category (minimum score):	**60**	

Asset Management



Asset Management

Conclusions

- Priority ranking identifies most advantageous maintenance activities in terms of dam safety
- Method permits good overview of dam condition and behavior
- Values Dam Safety Engineer technical judgment
- Uniform procedure
- Flexible and adaptable

Asset Management

Thank you!